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ORIGINAL PAPER

Soil carbon and nitrogen dynamics linked to *Piliostigma* species in ferugino-tropical soils in the Sudano-Sahelian zone of Burkina Faso, West Africa

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Abstract: In the Sudano-Sahelian zone of Burkina Faso, *Piliostigma reticulatum* (DC) Hochst and *Piliostigma thonningii* (Schumach) are precursor species of fallow land colonization and they are used by rural villagers. The present study aimed to assess the contribution of *Piliostigma* species to soil quality improvement. We quantified organic carbon, total nitrogen, soil microbial biomass, soil basal respiration and metabolic quotient from soil samples taken under and outside *Piliostigma* canopies. We used one-way ANOVA to test for differences in the above parameters between locations (beneath and outside *Piliostigma* canopies). We recorded increased total organic carbon under *Piliostigma* from 31%–105% and in total nitrogen from 23%–66%. Microbial biomass was 13%–266% higher beneath canopies as compared to outside canopies. Basal respiration was also higher beneath canopies. The chemical elements varied by class of soil texture. Metabolic quotient (qCO_2) was significantly correlated to clay ($r = 0.80$) and silt ($r = 0.79$) content. *Piliostigma* stands produced abundant litter due to their leaf biomass. Thus, they contribute to improved total organic carbon and total nitrogen content in the different phytogeographic zones and improve soil fertility

Keywords: *Piliostigma*; phytogeographic zone; soil; carbon; nitrogen; microbial biomass

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Introduction

Agriculture is an important economic activity in Burkina Faso. Cereals, namely millet, sorghum and maize, are the most widely grown crops and cover about 90% of cultivated areas (MEDEV/ DGEP 2005). The production system is traditional and led by small farmers who often cannot afford to apply fertilizers and consequently overexploit soil resources, causing depletion of soil nitrogen and phosphorus (Duponnois et al. 2000). Gnankambary et al. (2008) reported that tropical soils are typically poor and their phosphorus content is not available to plants. Agroforestry can mitigate the economic impacts of poor soils because woody components of the agroforestry system improve soil fertility and thus enhance crop yields (Boffa et al. 2000; Bayala et al. 2003). Species such as *Vitellaria paradoxa*, *Faidherbia albida*, *Parkia biglobosa,* common in agroforestry systems, have been the subject of many studies aiming to evaluate their contribution to soil fertility management and crop yield improvement (Depommier 1996; Boffa et al. 2000; Kho et al. 2001; Bayala et al. 2003; Traoré et al. 2007; Gnankambary et al. 2008).

Nowadays, due to changing climatic conditions, gregarious woody species such as *Piliostigma reticulatum and P. thonningii*, are increasingly used in agroforestry systems in Burkina Faso (Albergel et al. 1984; Millogo / Rasolodimby 2001). These

species are usually left on the field after clearing of old fallows for agriculture, where they are used by farmers as indicators of recovered fertility. However the contribution of these species to soil fertility and crop yield improvement has not been thoroughly investigated (Kizito et al. 2007; Lufala et al. 2008; Lufala et al. 2009; Dossa et al. 2009; Diedhiou et al. 2009). Our study aimed to evaluate the effect of *Piliostigma* species on soil fertility in different phytogeographic zones of Burkina Faso. It is crucial to assess the effect of these species on soil organic matter dynamics for improved management of agro-ecosystems. Our study also documents scientific evidence for the use of these species as indicators of fertility restoration on fallow lands. Microbial biomass and respiratory intensity are useful indicators of soil quality (Eaton 2001). There is significant difference in soil fertility between locations (beneath and outside canopies) for some *Acacia* species (Traoré et al. 2007). In the present study, we aim to test the following hypotheses for *Piliostigma* species: (1) Soil C, N and P contents are higher beneath *Piliostigma* canopies compared to outside canopies; (2) the microbial biomass and soil respiration are more important under *Piliostigma* canopies compared to outside canopies; (3) The intensity of microbial activities of soils under *Piliostigma* canopies varies across phytogeographic zones.

Material and methods

Study area and sites characteristics

The experimental sites were on fallow lands or natural vegetation 15 to 30 years old, located in Sahelian and Sudanian zones (Fig. 1). Annual rainfall ranges from 500–900 mm. The distribution of the five research sites in the phytogeographic zones, and their dominant species are presented in Table 1. Most common soil types are lithosoils in the north and tropical ferruginous soils in the centre (north and south Sudanian zone). Mean daily minimum and maximum temperatures range from 16–32°C in January (the coldest month) and from 26–40°C in April (the hottest month).

Table 1. Species distribution in research sites and phytogeographic zone

Research sites	Phytogeographic zone	Dominant species
1	Sub Sahelian	*P. reticulatum*
2	North Sudanian	*P. reticulatum*
3	North Sudanian	*P. reticulatum* + *P. thonningii*
4	South Sudanian	*P. reticulatum* + *P. thonningii*
5	South Sudanian	*P. thonningii*

Soil samples were collected beneath and outside *Piliostigma* canopies at each of five sites. Soils were sampled at four locations at each tree, one at each of the four cardinal directions from the base of the tree. The characteristics of *Piliostigma* trees where soils were sampled are given in Table 2. Soils were sampled from the upper 20 cm of soil depth using an auger.

For soil texture studies, sampling was done at only two locations; beneath the canopy and one meter from the trunk, and outside the canopy. Soil sampled for biological analyses was kept in containers that maintained the ambient temperature at the time of sampling, while the other samples were air-dried for physico-chemical studies.

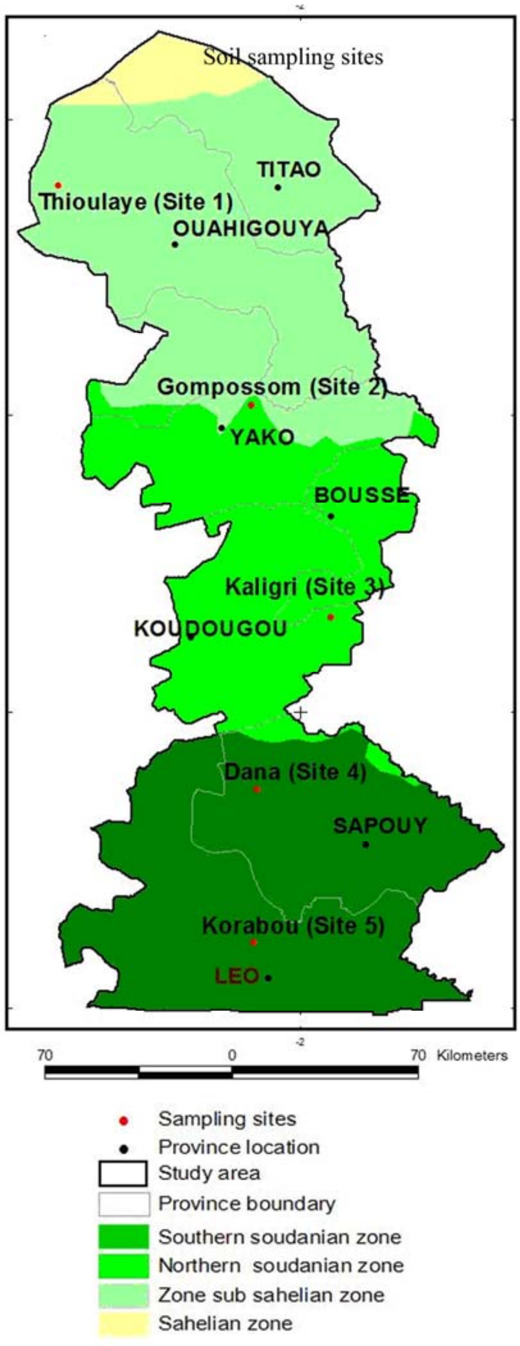


Fig. 1: Localization of study's sites

Soil analysis

Physical and chemical properties

Soil texture, total organic carbon, total nitrogen, total phosphorus and pH(H_2O) were analyzed using the following methods:

• Soil texture was studied using the international Robinson's pipette method to determine the percentage of mineral particles. Fine soil (< 2 mm) was used after pretreatment, grinding, and destruction of the organic matter by hydrogen peroxide (H_2O_2). We distinguished three soil textures: granulometric clay, silt and sand.

• Total organic carbon was determined using the method of Walkey and Black (1934);

• Total nitrogen was determined using Kjeldahl's method (Houba et al., 1988);

• Total phosphorus was determined using an automatic sensor and the same extraction method as for total nitrogen;

• pH was measured by direct use of an electrode in a diluted soil solution (soil:water mixed at 1: 2.5).

• Soil sensibility (St) was determined using the method of Pieri (1989)

$$St = \frac{MO \times 100}{A + Lf}$$

where, *MO* = Organic Matter; A = argile (clay); Lf = Limons fins (fine silt). St < 5, we interpreted as physically degraded soil, very sensitive to erosion; 5 < St < 7 we interpreted as soil at high risk of physical degradation; St > 7, soil with no risk of degradation

Table 2: Characteristics of *Piliostigma* individuals under which soil sampling was done

Sites	Species	Stems number	Total height (cm)	Canopy diameter (cm)
1	*P. reticulatum*	2 ± 2	213.96 ±76.96	217.32 ± 110.02
2	*P. reticulatum*	4 ± 3	172.62 ± 56.63	166.91 ± 74.88
3	*P. reticulatum*	3 ± 3	177.10 ± 72.51	153.10 ± 82.24
	P. thonningii	3 ± 2	215.34 ± 69.80	156.01 ± 78.88
4	*P. reticulatum*	3 ± 2	181.86 ± 74.89	122.96 ± 60.92
	P. thonningii	2 ± 1	209.58 ± 67.24	131.20 ± 57.48
5	*P. thonningii*	2 ± 1	253.32 ± 89.20	201.02 ± 109.55

Note that stems numbers were rounded to avoid decimals in the figures

Microbial biomass

The chloroform-fumigation - incubation (CFI) method is suitable for fine texture soils with low organic carbon content (Kaiser et al. 1992). In our experiment, 200 g of soil were divided into two fractions of 100 g each and adjusted to 60% of water holding capacity (WHC). The first fraction was fumigated for 24 h with trichloromethane ($CHCl_3$). After removing the fumigation agent by repeated evacuations (washing), samples were readjusted to 60% WHC and incubated together with the non-fumigated soil samples using Sodium Hydroxide (NaOH, 0,5N) to trap the CO_2 released from the soil (Wang et al. 2003). To simulate ambient conditions in Sudano-Sahelian zones, incubation temperature was set at 28ºC and the incubation time reduced to seven days (Chaussod et al. 1986). When incubation was terminated, an excess of barium chloride ($BaCl_2$) was added to the NaOH solution to precipitate carbonate (CO_3^{2-}) and the rest of the NaOH was neutralized with hydrochloric acid (HCl 0.5 N) using phenolphthalein as the indicator. Soil microbial biomass (C_{mic}) was calculated by dividing the difference between CO_2 production of fumigated and non-fumigated soils by a correction factor Kc = 0.41 (Nicolardot et al. 1984).

Soil basal respiration

Soil basal respiration (Cresp) was determined using 100 g of non-fumigated soil and the CO_2 released was measured daily for 21 days as described above.

Metabolic quotient (qCO_2)

The metabolic quotient (qCO_2) corresponds to soil specific respiration and was estimated from the ratio of soil basal respiration to soil microbial biomass.

Relative carbon mineralisation rate

This was calculated as the ratio between the accumulated basal respiration during the 21 days and total organic carbon.

Data analysis

Significant differences in soil parameters and activities (soil microbial biomass, soil respiration and metabolic quotient) between locations (beneath and outside canopy) were tested using one way analysis of variance. For basal respiration which was measured daily for 21 days, we used one-way repeated measures analysis of variance to test change of respiration between locations. The homogeneity of variance assumption was checked using Mauchly's test of sphericity, and, when violated, the degrees of freedom for testing the significance of the within-subject factors were adjusted using Huynh–Feldt correction factor, which is less biased than other correction factors (Davis, 2002). Pearson's correlation was used to analyze linear relationships between variables. Results of the statistical analyses were considered significant at $p < 0.05$. These statistical analyses were performed using Statistica (Version 06).

Results

Soil texture

In general, there was no significant difference between locations with respect to the three soil physical parameters measured (clay, sand and silt percentage); but soil texture generally tended to be finer outside than beneath *Piliostigma* canopy (Table 3). Clay content varied from 15%–26 % beneath canopies and 17%–33% outside canopies. Sand content varied from 44%–59% under canopies and from 39% to 60 % outside canopies. The corresponding figures for silt content were 19%–33% vs. 24%–42 %. Soil texture showed therefore, a balance between the two locations (beneath versus outside *Piliostigma* canopies). Considering all study sites, site 1 in the sub-Sahelian zone showed generally greater variation in soil texture between the two locations (be-

neath versus outside canopies) while site 4 in the south-Sudanian zone showed less variation in texture classes.

Table 3. Clay, sand and silt content under *Piliostigma* and outside canopy

Sites	Species	Clay rate (%)		Sand rate (%)		Silt rate (%)	
		Under canopy	Outside Canopy	Under canopy	Outside Canopy	Under canopy	Outside Canopy
1	P. ret	26± 15	33 ± 14	54 ±15	42 ± 14	19 ±1	25 ± 0
2	P. ret	23 ± 5	24 ± 6	44± 13	39 ± 9	33 ± 8	42 ± 14
3	P. ret	19 ± 4	17 ± 3	59 ± 6	59 ± 6	22 ± 7	24 ± 4
	P. th	25 ± 6	17 ± 3	54± 13	60 ± 7	22± 11	24 ± 5
4	P. ret	15± 10	19 ± 13	58± 11	56 ± 13	25 ± 4	24 ± 6
	P. th	16 ± 7	18 ± 8	56± 13	55 ± 13	28 ± 7	28 ± 8

P. ret = *P. reticulatum*; P. th = *P. thonningii*

Total organic carbon, total nitrogen content and C/N ratio

Total organic carbon and total nitrogen content were significantly higher beneath *P. reticulatum* canopies than outside canopies, except at sites 4 and 5 (in the south Sudanian zone) where significant differences between the two locations were not found (Table 4). Organic carbon content at site 2 (north-Sudanian zone), for instance, was 105% higher beneath the *P. reticulatum* canopy. Total nitrogen content also was 27%–66% higher beneath the *P. thonningii* canopy at site 3.

Table 4. Total organic carbon and total nitrogen contents variation under and outside *Piliostigma* species canopies (n = 4).

Species	Sites	C_{total} ($g \cdot kg^{-1}$)		N_{total} ($g \cdot kg^{-1}$)	
		Under canopy	Outside canopy	Under canopy	Outside canopy
P. reticulatum	1 Sub Sahel	11.83± 1.93	6.58 ± 1.11*	1.40 ± 0.37	1.14 ± 0.24*
	2 North Sudan	16.87± 4.62	8.21 ± 3.21*	1.48 ± 0.28	1.81 ± 0.33*
	3 North Sudan	9.51 ± 4.78	6.04 ± 1.39*	0.88 ± 0.50	0.67 ± 0.27*
	4 South Sudan	7.78 ± 2.25	5.93 ± 1.72	0.63 ± 0.19	0.45 ± 0.29
P. thonningii	3 North Sudan	10.08 ± 5.12	6.19 ± 2.75*	0.93 ± 0.51	0.56 ± 0.40*
	4 South Sudan	7.14 ± 1.49	5.1 ± 1.21	0.62± 0.23	0.49 ± 0.14
	5 South Sudan	8.10 ± 1.03	8.73 ± 1.11	0.42 ± 0.13	0.50 ± 0.35

* = significant results

Irrespective of the *Piliostigma* species, no significant difference was found between the two locations (under versus outside canopy) with respect to the C/N ratio, except at site 2 where the under-canopy value was more than double that outside the canopy (Table 5).

Soil microbial biomass

For *P. reticulatum*, soil microbial biomass was significantly different between locations, except at site 2. It was 13%–147% higher under the *P. reticulatum* canopy than outside and ranged from 120.13 $\mu g \cdot g^{-1}$ to 253.10$\mu g \cdot g^{-1}$ under the canopy (Fig. 2).

For *P. thonningii*, there were significant differences between locations with respect to soil microbial biomass, except at site 4 (south-Sudanian zone). At site 3 (north-Sudanian zone) soil microbial biomass was higher under canopies (248 $\mu g \cdot g^{-1}$ vs. 93 $\mu g \cdot g^{-1}$) while the reverse situation was observed at site 5 (south-Sudanian zone) with 220% higher microbial biomass outside the canopy (Fig. 2).

Table 5. C/N ratio variation under and outside *Piliostigma* species canopies

Species	Sites	C_{total}/ N_{total}	
		Under canopy	Outside canopy
P. reticulatum	1 Sub Sahel	8.62 ± 0.91	5.83 ± 0.50
	2 North Sudan	11.31 ± 1.83	4.47 ± 1.39*
	3 North Sudan	13.09 ± 6.66	9.83 ± 3.45
	4 South Sudan	12.57 ± 1.41	15.45 ± 6.17
P. thonningii	3 North Sudan	11.73 ± 4.30	12.14 ± 7.31
	4 South Sudan	12.00 ± 1.92	10.53 ± 1.32
	5 South Sudan	20.18 ± 3.86	20.74 ± 12.70

* = significant results

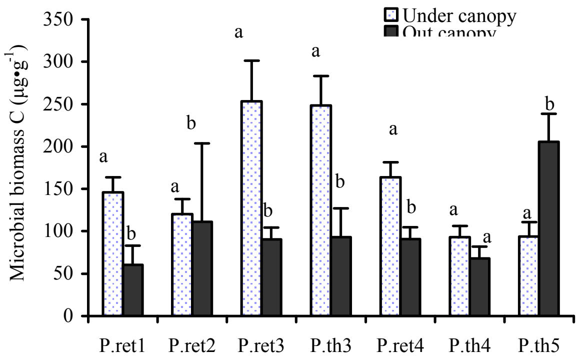


Fig. 2 Microbial biomass variability under and outside *P. reticulatum* (P. ret) and *P. thonningii* (P. th) canopies. Means ± standard errors; n = 4. In a given bars with different letters are significantly different. (1= site 1, 2= site 2, 3= site 3, 4= site 4, 5= site 5)

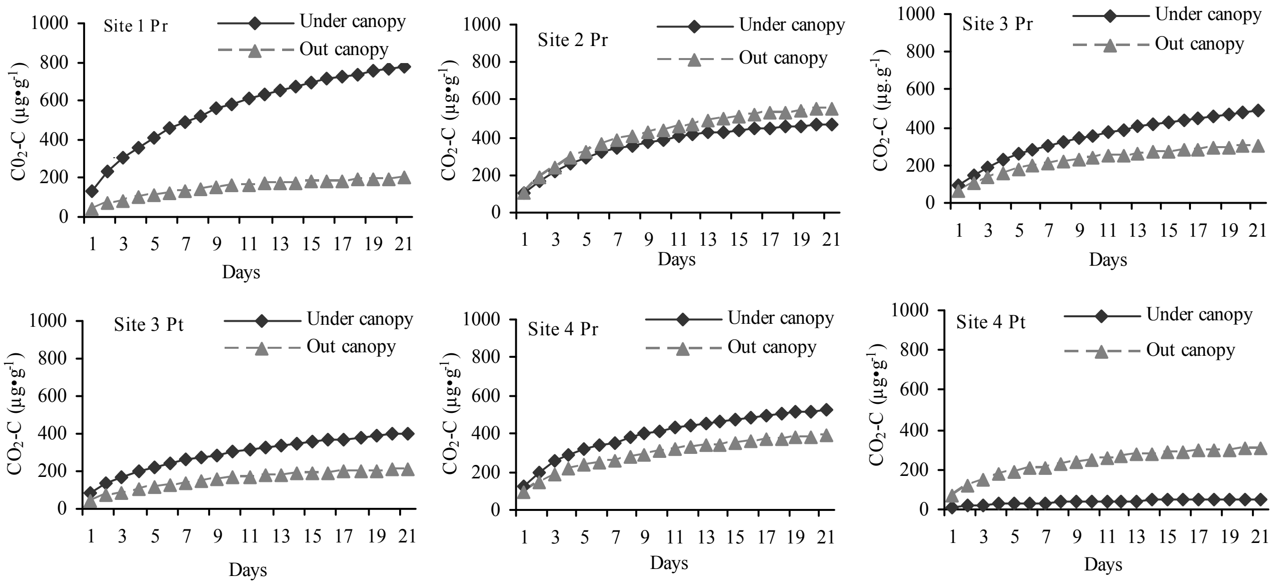
Basal respiration

At all sites, there was significant increase in CO_2 release throughout days (Table 6, Fig. 3). However, respiration did not differ significantly between locations, although the daily measure at site 1 was substantially higher under *P. reticulatum* canopies than outside.

Metabolic quotient (qCO_2)

Except at site 1 (sub-Sahelian zone) metabolic quotient did not differ significantly between locations (Fig. 4). At site 1, metabolic quotient under *P. reticulatum* canopy was 132% lower than outside. On average, metabolic quotient or soils specific respiration ranged from 57–155 C-CO_2 mg·g^{-1} biomass per day under *P.*

thonningii canopies and from 51–90 C-CO_2 mg·g^{-1} biomass per day outside canopies.



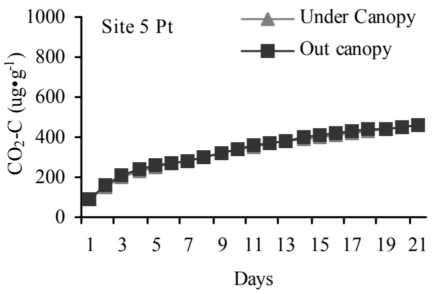


Fig. 3 CO_2-C respired under and outside *Piliostigma* canopy during 21- days of incubation subscripts.
Pr = Piliostigma reticulatum ; *Pt = Piliostigma thonningii*

Table 6. Summary of repeated measures ANOVA for testing the significance of the between (location)- and within-subject (day and day*location) effects on basal respiration

Site	Species	Study factor	F	P
1	*P. reticulatum*	Day	65.616	0.000
		Location	3.815	0.123
		Day*Location	4.933	0.061
2	*P. reticulatum*	Day	21.128	0.000
		Location	0.459	0.535
		Day*Location	0.420	0.681
3	*P. reticulatum*	Day	44.801	0.000
		Location	3.035	0.132
		Day*Location	1.119	0.350
3	*P. thonningii*	Day	38.237	0.000
		Location	3.508	0.110
		Day*Location	3.829	0.071
4	*P. reticulatum*	Day	62.629	0.000
		Location	1.099	0.335
		Day*Location	1.438	0.276
4	*P. thonningii*	Day	62.349	0.000
		Location	2.089	0.198
		Day*Location	2.143	0.162
5	*P. thonningii*	Day	47.281	0.000
		Location	0.002	0.970
		Day*Location	0.252	0.909

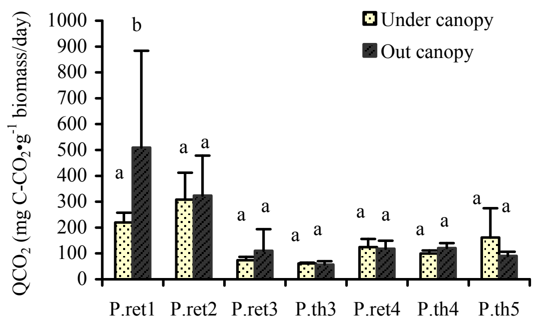


Fig. 4 Variability of metabolic quotient under and outside *P. reticulatum* (P. ret) and *P. thonningii* (P. th) canopy. In a given site graphs with different letters are significantly different (1= site 1, 2= site 2, 3= site 3, 4= site 4, 5= site 5)

Variability of Cresp after 21 days per total organic carbon unit

The mineralization of carbon by total organic carbon unit varied from 29–67 µg·g^{-1} under *P. reticulatum* canopies and from 31–68 µg·g^{-1} outside canopies. Under *P. thonningii* canopies, average mineralization varied from 50–63 µg·g^{-1} while it ranged from 41–60 µg·g^{-1} outside canopies. At site 1 (sub-Sahelian zone) and 2 (north-Sudanian zone), the value under canopies was significantly lower than the value outside canopies (Fig. 5). Apart from these two sites, no significant differences were observed.

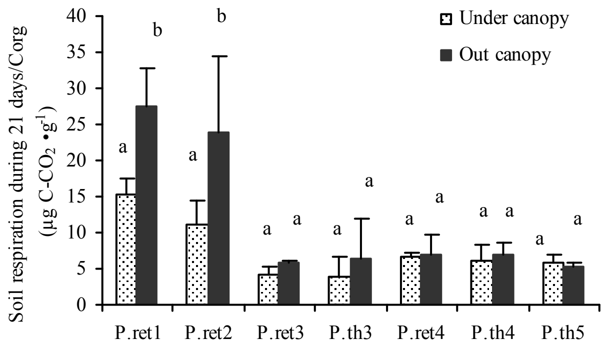


Fig. 5 Variability of respiration at the end of 21 days per organic carbon unit under and outside *P. reticulatum* (P. ret) and *P. thonningii* (P. th) canopy. Bars with different letters are significantly different (1= site 1, 2= site 2, 3= site 3, 4= site 4, 5= site 5).

Interactions between variables

Relationship between soil physico-chemical parameters

Soil clay content is highly related to silt content, organic carbon (C.org) and total nitrogen content (Ntotal). C/N ratio and pH (H_2O) are also highly related to clay, silt C.org and Ntotal (Table 7).

Table 7. Relationship (Pearson correlations) between soil physico-chemical parameters

Variables	Clays	Sands	Silts	C.org	Ntotal
Clays	1.00	-0.04	**0.69***	**0.77***	**0.80***
Sands	-0.04	1.00	-0.01	0.47	0.47
Silts	**0.69***	-0.01	1.00	0.73	**0.79***
C.org	**0.77***	0.47	0.73	1.00	**0.96***
N.total	**0.80***	0.47	0.79	**0.96***	1.00
C/N	**0.70***	0.45	0.74	**0.88***	**0.91***
Ptotal	**0.80***	0.48	0.79	**0.96***	1.00
pH(H_2O)	**0.80***	0.47	0.79	**0.96***	1.00

*= significant results

Relationship between soil physico-chemical and biological parameters

Carbon mineralisation rate at 21 days was significantly positively correlated to silt content, Ntotal, C/N, Ptotal and pH(H_2O) although the correlation coefficient was relatively low (Table 8). Metabolic quotient (qCO2) was significantly positively and strongly correlated to soil physical parameters such as clay (r = 0.8) and silt (r = 0.79) content.

Table 8. Relationship between soil physico-chemical and biological parameters

Variables	Cres(7)	Cres (21)	Cres(7)/ Corg	Cres(21) /Corg	Cmic	Cmic/ Corg	qCO2
Clays	-0.25	-0.27	0.37	0.17	-0.16	0.16	**0.80***
Sands	0.12	0.11	0.34	0.25	-0.23	0.16	0.48
Silts	-0.26	-0.30	0.37	**0.16***	-0.17	0.27	**0.79***
Ntotal	-0.19	-0.22	0.52	**0.27***	-0.27	0.30	1.00
C/N	-0.11	-0.16	0.51	**0.28***	-0.37	0.23	**0.92***
Ptotal	-0.19	-0.22	0.52	**0.27***	-0.27	0.30	1.00
pH(H2O)	-0.19	-0.22	0.52	**0.27***	-0.27	0.30	1.00
Cres(7)	1.00	**0.99***	0.43	**0.54***	-0.07	-0.31	-0.19
Cres(21)	**0.99***	1.00	0.39	0.53	-0.01	-0.32	-0.22
Cres(7)/Co	0.43	0.39	1.00	**0.95***	-0.05	0.10	**0.52***
Cres(21)/Co	**0.54***	0.53	0.95	1.00	0.08	0.01	**0.27***
Cmic	-0.07	-0.01	-0.05	0.08	1.00	0.20	-0.28
Corg	-0.21	-0.24	0.43	**0.19***	-0.25	0.28	**0.96***
Cmic/Corg	-0.31	-0.32	0.10	0.01	0.20	1.00	0.30
qCO_2	-0.19	-0.22	0.52	**0.27***	-0.28	0.30	1. .00

*= significant results

Discussion

Soil texture

Considering all studied sites, there were no significant differences between locations (under versus outside canopy) with respect to soil texture. However, all locations taken together, sand and silt contents were higher than clay content at all sites: these sites appear to be sandy-silt soils. Although no significant difference was observed, woody canopies are important for soil texture because canopies reduce the impact force of raindrops and thus reduce lateral water erosion and selective erosion substantially (Traoré et al. 2007). Moreover, soil humidity is higher under *Piliostigma* canopies than outside (Kizito et al. 2007). These processes could be at the origin of the phenomenon of infiltration of the fine particles and their deposit at depth, whereas outside canopy the erosion of the coarse elements is more important. This phenomenon is more important around

Piliostigma species with low canopies and bushy stature (Arbonnier 2002). In the north-Sudanian zone, we observed an important biological activity of the termites characterized by the existence of termite mounds under *Piliostigma* species. This biological activity would entail an ascent of the thin elements of the underlying horizons toward the surface (Traoré et al. 2007) and explain the strongest presence of clays under canopies in the north-Sudanian zone.

Carbon and Nitrogen contents

Irrespective of phytogeographic zone, *P. reticulatum* increases organic carbon and nitrogen contents in its area of distribution. Hook et al. (1991) documented that the spatial variation of primary producers and their distribution on soil are the two important factors explaining the variation of edaphic properties under woody vegetations in dry areas. The same was true for *P. thonningii*, except in the south-Sudanian area, where a relative trend toward increased organic carbon content outside canopies was observed. Our results corroborate those of Diedhou et al. (2009) for the semi-arid area of Senegal, where C and N content were higher under *Guiera senegalensis* and *Piliostigma reticulatum* canopies than outside canopies. Carbon content increase under *Piliostigma* canopy can be explained by the transformation of the abundant litter and root biomass beneath these trees. Moreover, some trees have more litter beneath than on areas outside their canopies due to the annual herbaceous biomass accumulated (Traoré et al. 2007). Breman and Kessler (1995), Tanako and Hashimoto (2006), and Jandl et al. (2007) reported that woody vegetation contributed significantly to carbon sequestration in arid and semi-arid areas. Higher carbon and nitrogen content beneath *Piliostigma* canopies could also be explained by the chemical composition of *Piliostigma* leaves. Indeed Iyamuremye et al. (2000) showed that *P. reticulatum* leaves have high total nitrogen and hemicellulose and low lignin content compared to many plants in the agroforestry system in Senegal. Soil carbon content is variable from one area to another probably due to the degree of organic matter accumulation in the soil. This depends on the quantity and quality of the organic substances and on the rate of decomposition by microorganisms (Sagar et al. 1999).

The dynamics of organic matter in soil are under the control of several physical, chemical and biologic factors. In our study, a very important variation of climatic factors (e.g. rainfall, temperature, atmospheric humidity) from the north to the south (Les atlas Jeune Afrique, 1998) is an important factor that may affect organic matter decomposition. Many authors point out average annual temperature as important factor impacting the dynamics of soil organic carbon (Poste et al. 1982; Tremblay et al. 2002; Wang et al. 2004).

In addition to these factors that cause variation in carbon content between sites according to tree species, it is necessary to consider soil management issues. Our study sites were old fallow lands subjected to livestock grazing, wood cutting and annual bush fires. Many studies have demonstrated the negative influences of management practices (e.g. land use and bush fire) on the chemical, biological and physical properties of soils (Imeson et al. 1992; Inbar et al. 1997; Thomas et al. 1999; Pardini et al. 2002 and 2004). Also, the different cycles of C and N are intimately dependent on the physiology of the plants and microorganisms. Soil microorganisms play an important role on carbon availability as source of plant nutrients (Zak et al. 1990). They are the main regulators of carbon dynamics in soils.

In the south-Sudanian zone (site 5), *P. thonningii* is found in shrubby savannas with high humidity, which reduces temperature variation and leads to reduced activity of microorganisms. This could explain the low organic carbon content under canopies.

C/N ratio

We documented a general trend toward higher C/N ratios under *P. reticulatum* canopies than outside except at site 4 (south-Sudanian zone) where the C/N ratio was lower beneath than outside the canopy. But the difference was significant only at site 2. Breman and Kessler (1995) reported that litter under trees is composed of lignin that inhibits the processes of mineralisation. In the south-Sudanian area of *P. reticulatum* and the north- and south-Sudanian area of *P. thonningii*, organic compounds under canopies appear to decompose more readily. These results might be explained by more favorable environmental conditions, litter with higher nitrogenous content and the composition of the microorganism assemblages. We note, however, that C/N ratios did not vary substantial in most cases between the two locations (beneath versus outside canopies).

In the 0–20 cm soil horizon at our study site we found many fine roots of *Piliostigma* that were continuously renewed. Dead roots also play an important role in the rate of metabolism of organic carbon and total nitrogen in soils under *Piliostigma* (Yoni, 2005): enzyme activity was greater beneath canopies than outside (Diedhou et al. 2009).

In the sub-Sahelian and north-Sudanian area (sites 1 and 2), *P. reticulatum* stands had C/N ratios less than 12, indicating that the organic matter at these sites is continuously improving. Soils beneath and around *P. thonningii* had the highest C/N ratios, increasing from north to south. Batjes and Dijkshoorn (1999) noted that a C/N ratio between 12 and14 is an indicator of low soil nitrogen content. The results of our granulometric studies showed relatively low clay contents under canopies that could also explain the high C/N ratios observed in *Piliostigma* savannas. Hassink et al. (1993) concluded that physically protected organic matter yields a lower C/N ratio than does unprotected protected organic matter. Many authors also reported that the texture of soil is an important parameter influencing the availability of organic carbon (Anderson et al. 1981; Feller et al. 1981; Chaussod et al. 1986; Traoré et al. 2007). The fact that C/N ratios under *Piliostigma* canopies increase from north to south, could be explained by an increase in mean annual precipitation and a decline in mean annual temperature that are important factors for humus mineralisation (Yimer et al. 2006). In *P. thonningii* savannas, the temperature variation is not substantial, leading to high C/N ratio which is a proof of low litter decomposition. Generally, the C/N ratios around *Piliostigma* were low,

probably due to high nitrogen content under *Piliostigma*, which is a consequence of low immobilization of nitrogen derived from *Piliostigma* leaves (Iyamuremye et al. 2000).

Soil microbial biomass and basal respiration

Soil microbes transform soil organic matter into storage nitrogen. Microbial biomass is a valuable indicator of changes in soil quality (ITAB, 2002). Microbial biomass (Cmic) beneath *Piliostigma* canopies was consistently higher than outside, except for *P. thonningii* at site 5 (south-Sudanian zone). This pattern of microbial biomass distribution (under and outside canopies) dictates the distribution of total carbon and total nitrogen as demonstrated by our results and the relationships between these different variables. According to ITAB (2002) and Lee Jose (2003), the quantity of microbial biomass and its activity depend on organic matter quantity and notably its free fraction. Contrary, Nguyen et al. (2004), concluded that microbial biomass and its activity are rather a function of soil quality expressed by the C/N ratio and pedoclimatic conditions. The rather weak and negative relationships between microbial biomass and organic carbon or total nitrogen (Table 8) does not mean that these parameters are not sensitive indicators of changes in the soil (Hargreaves et al., 2003); they are instead the results of important variations due to soils management, for example the effects of bush fires (Brookes and Mc Grath 1984; Powlson et al., 1987; Hernadez-Hernandez and Lopez-Hernandez, 2002). The mineralisation beneath *Piliostigma* canopies is generally more important than that outside canopies because of higher carbon and nitrogen content under the canopy. The progressive reduction of organic carbon and total nitrogen at the site (from 7 to 21 days), also explains the progressive decrease of mineralization. Our results corroborate those of Iyamuremye et al. (2000) who established a linear relation between CO_2 release and incubation time. The positive relationship between these different variables also marks a decrease in mineralization time. Many authors (Feller et al. 1981; Kaiser et al. 1992; Wang et al. 2003) showed that soil respiration is determined by the availability of organic substrates. The microbial biomass and favorable conditions of temperature and humidity are determinants of the rate of mineralization (Fardoux et al. 2000). The decreasing relationship between Cresp(7), Cresp(21) and Cmics are the results of this interdependence.
At sites 4 and 5, there was no difference in CO_2 release between locations (under *P. thonningii* canopy and outside canopy). Sites 4 and 5 were located in the south-Sudanian zone and were characterized by higher rainfall with increasing trend from site 4 to site 5. The low CO_2 generally observed around *P. thonningii*, could be explained by unfavourable environmental conditions for microbe activity.

Among the conditions that determine microbial activity, pH constitutes an important element. Our study sites were characterized by acidic to relatively neutral pH. According to ITAB, (2002) and Yoni (2005), pH influences biomass size and microbe diversity: as soil acidity increases microbial biomass decreases. The negative relationship between pH (H_2O) and microbial biomass (Table 8) shows the difficult conditions for microbes at our study area. Moreover, many authors stress that the chemical substrate influences the composition of microbe assemblages (Diedhiou et al., 2009; Heal et al. 1997) and therefore the degrees of decomposition (Elliot and Elliot 1993). The Cmic/Corg ratio which is a sensitive indicator of carbon availability and efficiency of use of the substratum (Kaiser et al. 1992), gave values between 2 and 7.5%. Our results corroborate the works of Traoré et al. (2007) who recorded Cmic/Corg values ranging from 2- 7% for eastern Burkina Faso.

Metabolic quotient

The metabolic quotient is a measure of substrate accessibility to microorganisms (Hernandez-Hernandez and Lopez-Hernandez, 2002). Our results show low metabolic quotients under *Piliostigma* canopies at site 1. For Insam (1990), the increase of the respiratory quotient is synonymous with a decline in the efficiency of organic matter use by soil microorganisms. Under woody canopies, an important fraction of the substrate is incorporated in the biomass and little organic carbon per unit of biomass is lost to respiration (Traoré, 2008). The substantial relationship between qCO_2 and Cmic/Corg corroborates these results. Hernandez-Hernandez and Lopez-Hernandez (2002) concluded that elevated metabolic quotients are due to the stability of aggregations. Traoré et al. (2007) noted that microbial community diversity also influences the efficiency of the substrata.

The metabolic quotient and respiration (7 and 21 days of incubation) per organic carbon unit increase outside canopies. These variables are strongly dependent on soil texture, especially clay content. Our results show a positive relationship between the metabolic quotient and respiration per organic carbon unit with the microaggregats. These results can be explained by differences in organic substrate accessibility to microorganisms. Moreover, the protective effect of clay on organic matter is a function of the type of clay. Our study area is marked by low clay content under canopies except at the north-Sudanian area. The organic substrate is thus easily accessible to microorganisms. Traoré et al. (2007) reported that the electrostatic effect depends on the nature of clays and is more pronounced for clays dominated by smectic than kaolinitic elements. Moreover, Hien (2004) reported that clays of tropical ferruginous soils had kaolinite nature of type 1:1, resulting in low capacity of cationic exchange and rapid mineralization.

Conclusion

There was no significant effect of location on soil texture. Sand, silt and clay content under *Piliostigma* canopies was not significantly different from that outside canopies. The abundant litter accumulated from the leaves of *Piliostigma* trees contributed to increased organic carbon and total nitrogen content under canopies. In sub-Sahelian and north-Sudanian zones, which support *P. reticulatum* savannas, the environmental conditions are favorable to microbial activity. Microbial activity is lower in *P. thonningii* savannas in the south-Sudanian zone. Under *Piliostigma* cano-

pies, organic matter and microbial biomass were greater than outside canopies.

Given the fact that *Piliostigma* grows in areas that are prone to bush fire and if management practices reduce destruction of biomass by bush fire, these species can contribute to increased soil organic carbon and total nitrogen content and thus improve fertility of fallow lands.

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